CLEMENTINE II: A DOUBLE ASTEROID FLYBY AND IMPACTOR MISSION

RONALD J. BOAIN
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CA

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SYNOPSIS AND OBJECTIVES

o JPL HAS ANALYZED AND DEVELOPED FOR SDIO A PRELIMINARY MISSION DESIGN FOR A DEEP SPACE MISSION TO FLYBY TWO NEAR EARTH ASTEROIDS, EROS AND TOUTATIS. AS A PART OF THIS MISSION, THE POSSIBILITY OF CARRYING AND DEPLOYING A PROBE TO IMPACT TOUTATIS WAS ALSO ANALYZED AND FOUND FEASIBLE. THIS MISSION IS A CANDIDATE FOR SDIO's CLEMENTINE H.

o SDIO MISSION OBJECTIVES
- PROVIDE FOR SDIO A DEMONSTRATION OF AUTONOMOUS NAVIGATION TECHNOLOGY FOR CONTROLLING THE FLIGHT PATH OF A SPACECRAFT DURING A CLOSE ENCOUNTER WJTH TARGET ASTEROIDS
- DEPLOY A PROBE FROM THE SPACECRAFT ON APPROACH TO THE SECOND OF THE TARGET ASTEROIDS IN SUCH A WAY THAT THE PROBE IMPACTS THE ASTEROID AND THE CRATER IS IMAGED FROM THE PASSING SPACECRAFT
- PROVIDE iN-SPACE TESTS AND DENIONSTRATIONS OF NEW, ADVANCED TECHNOLOGIES UNDER DEVELOPMENT BY SDIO

o NASA MISSION OBJECTIVES
- OBTAIN THE FIRST IMAGES AND OTHER SCIENTIFIC MEASUREMENTS FROM A SPACECRAFT OF TWO IMPORTANT NEAR EARTH ASTEROIDS DURING A CLOSE FLYBY
- OBTAIN IMAGE CORROBORATION OF PRIOR EARTH BASED RADAR IMAGES OF TOUTATIS

HOW ACHIEVED?

- SPACECRAFT LAUNCHED ON A TRAJECTORY WHICH ENCOUNTERS BOTH EROS AND TOUTATIS.

- CLOSE FLYBYS AT EACH ASTEROID FOR HIGH RESOLUTION REMOTE SENSING

- A PROBE DEPLOYED ON APPROACH TO TOUTATIS, WHICH COLLIDES 15 TO 30 min. BEFORE SPACECRAFT CLOSEST APPROACH, CREATES A CRATER AND EJECTA CLOUD
  - ESTIMATED CRATER DIAMETER: 3 TO 10 meters
  - EJECTA SPEED NECESSARY TO REACH SPACECRAFT: 28 TO 56 m/s

- HIGH RESOLUTION OF IMAGERY OF THE IMPACT CRATER, EJECTA CLOUD, NEW-FRESH MATERIAL DURING ENCOUNTER WITH VISIBLE, UV, AND IR CAMERAS
  - 3-meter SPATIAL RESOLUTION ON THE SURFACE

- MASS SPECTROMETER AND DUST COLLECTOR/ANALYZER WILL MEASURE EJECTA PARTICLE SIZES, DISTRIBUTION, AND COMPOSITION DURING FLY-THRU

PROJECT ELEMENTS

- CLEMENTINE 1 SPACECRAFT (BUILT BY NRL) MODIFIED AND AUGMENTED BY ADVANCED PROPULSION
  - DRY WEIGHT (including propulsion inerts) = 496 lbm
  - POWER SUBSYSTEM OUTPUT AT 1 AU = 280 watts
  - MAXIMUM ANGULAR ACCEL. W/ POINTING = 104.7 mrad/s/s
  - MAXIMUM DATA STORAGE @ 20 Mbps ❑ 1.6Gbits
  - R3000 PROCESSOR

- CLEMENTINE I OPTICAL SENSORS (BUILT BY LLNL)
  - HIGH RESOLUTION IMAGER AND LIDAR
  - UV/VIS IMAGER
  - NEAR IR IMAGER
  - LWIR IMAGER

- LEAP PROJECTILE MODIFIED AND USED AS THE IMPACTOR PROBE
  - DRY WEIGHT ❑ 11.Olbm
  - WET WEIGHT = 22.7 lbm
  - ΔV CAPABILITY = 2000 m/s

- TITAN II G LAUNCH VEHICLE
  - THROW WEIGHT CAPABILITY TO ORBIT = 3720 lbm

- NASA's DEEP SPACE NETWORK FOR TRACKING

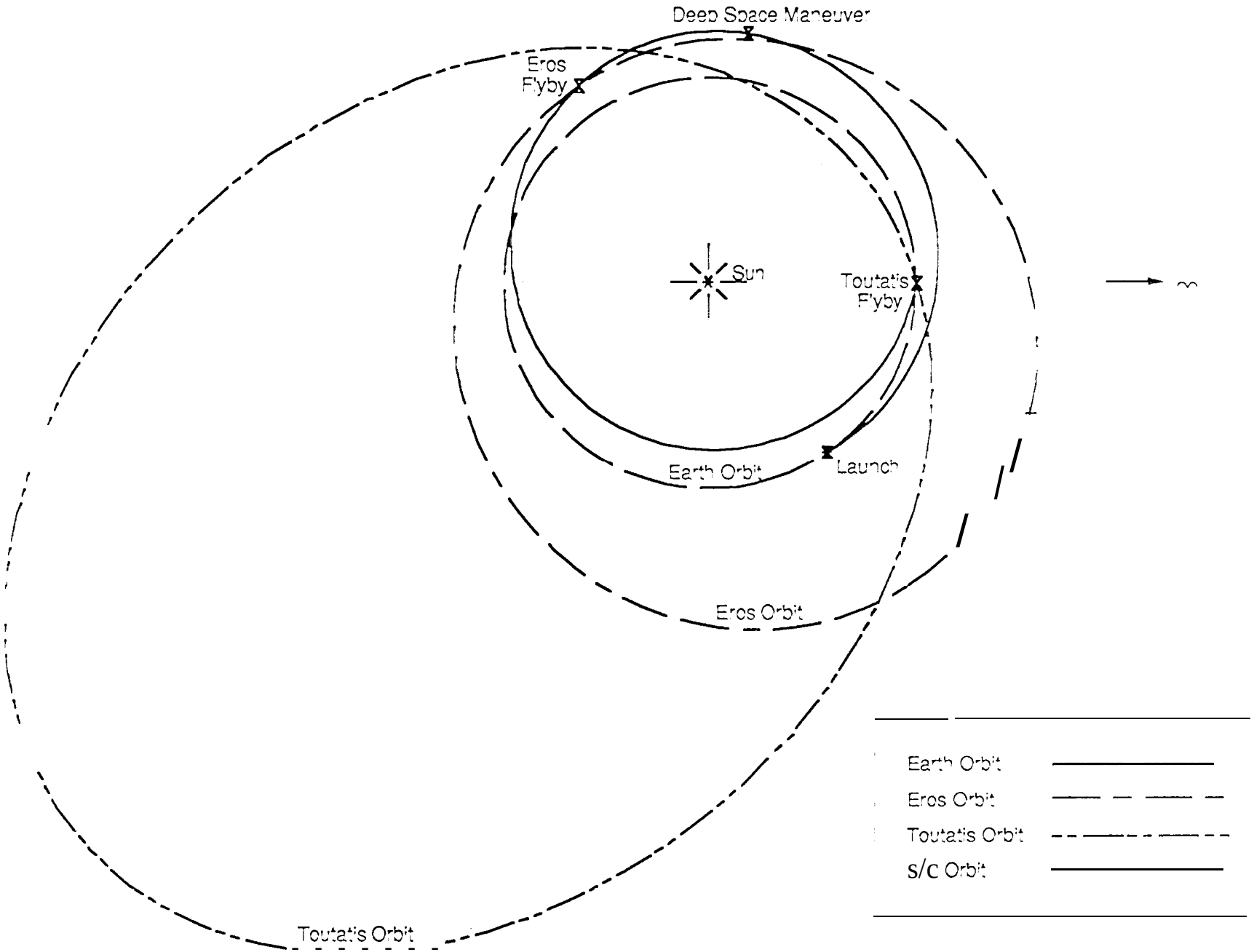
BRIEF MISSION DESCRIPTION

o MAJOR MISSION EVENTS
  EARTH DEPARTURE :28 JULY -7 AUGUST 1995
  - DEEP SPACE MANEUVER :12 JANUARY 1996
  - EROS ENCOUNTER :13 MARCH 1996
  - TOUTATIS ENCOUNTER :4 OCTOBER 1996

0 EROS ENCOUNTER SUMMARY
  - FLYBY SPEED ($V\infty$) = 8.44 km/s
  - MISS DISTANCE (b) = 30.0 km
  - PHASE ANGLE (Φ) = 119.4 deg
  - MAX ANGULAR RATE (ω) = 281.3 mrad/s
  - MAX ANGULAR ACCEL (α) = 51.4 mrad/s/s
  - GEOCENTRIC DISTANCE = 0.90 AU
  - HELIOCENTRIC DISTANCE = 1.13 AU

o TOUTATIS ENCOUNTER SUMMARY
  FLYBY SPEED ($V\infty$) = 17.8 km/s
  MISS DISTANCE (b) = 50.0 km
  - PHASE ANGLE (Φ) = 20.2 deg
  - MAX ANGULAR RATE (ω) = 355.6 mrad/s
  - MAX ANGULAR ACCEL (α) = 82.1 mrad/s/s
  - GEOCENTRIC DISTANCE = 0.21 AU
  I-IEL1OCENTRIC DISTANCE= 1.01 AU

Heliocentric ORBITS & TRAJECTORY



MISSION PERFORMANCE REQUIREMENTS

- **TEN-DAY LAUNCH WINDOW PERFORMANCE REQUIREMENTS**

EARTH DEPARTURE	LAUNCH ENERGY (km^2/s^2)	DECLINATION ASYMPTOTE (deg)	INJECTION ΔV (m/s)	DEEP SPACE ΔV (m/s)
07-28-95	6.40	-12.4	3502	1325
08-02-95	7.72	-11.9	3561	1265
08-07-95	9.32	-11.3	3631	1196

- **LAUNCH AV AND DEEP SPACE AV REQUIREMENTS VARY ACROSS THE LAUNCH WINDOW**
  - **INJECTION ΔV INCREASES WHILE DEEP SPACE AV DECREASES BY 129 m/s**
  - **CONSEQUENTLY, THE TOTAL DETERMINISTIC AV REMAINS CONSTANT AT 4827 m/s**

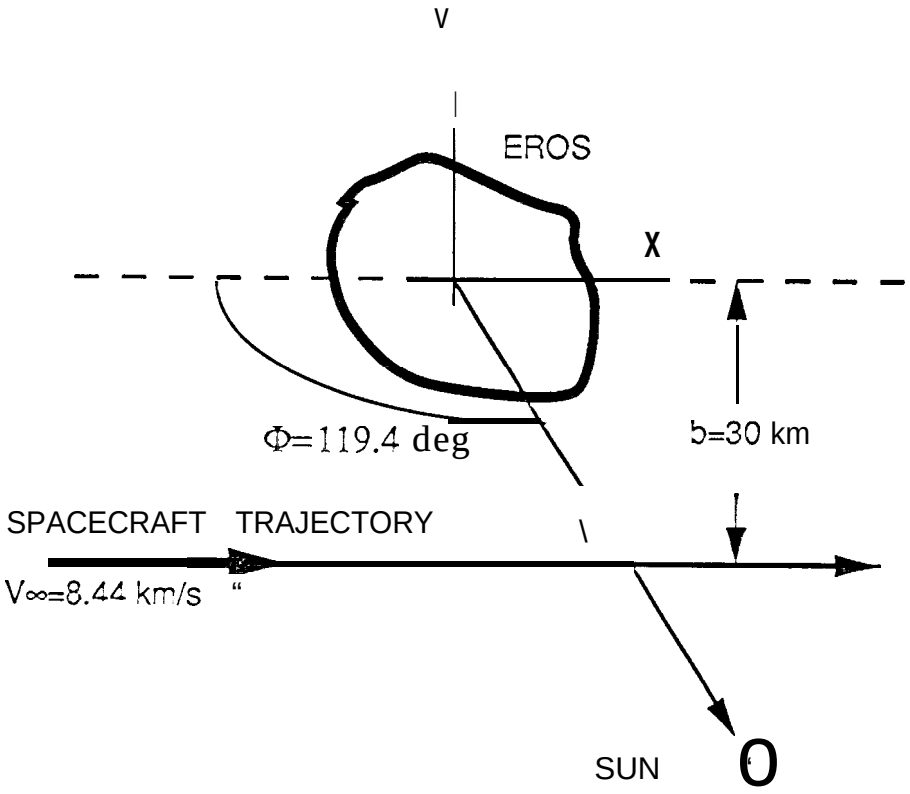
- **STATISTICAL AV REQUIREMENTS DETERMINED FROM A PRELIMINARY NAVIGATION ANALYSIS: 83 m/s**

- **THE ONLY REMAINING POTENTIAL LIEN ON THE AV BUDGET IS THE PENALTY DUE TO GRAVITY LOSSES DURING THE EARTH ESCAPE MANEUVER: MULTIPLE BURNS AND A PHASING ORBIT CAN MITIGATE THIS LIEN**

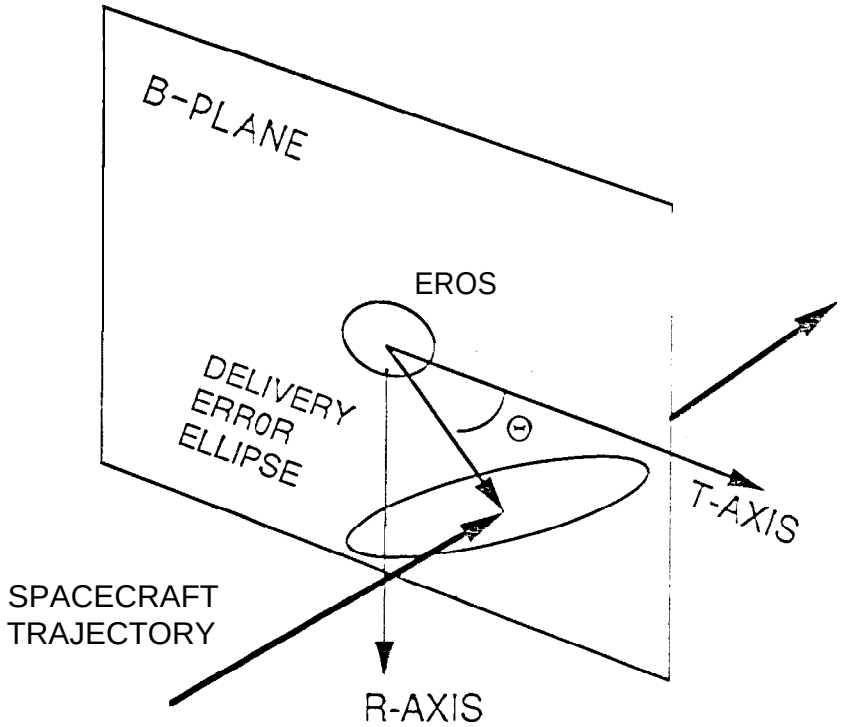
- **TOTAL AV REQUIREMENT ON THE SPACECRAFT FOR THE MISSION IS CONSERVATIVELY SELECTED AT 4827 + 123 = 4950 m/s**

EROS ENCOUNTER TRAJECTORY

TRAJECTORY PLANE SCHEMATIC



AIMPLANE SCHEMATIC



- o **Flyby** Speed (V_∞) = 8.44 **km/s**
- o Miss Distance (b) = 30.0 **km**
- o **Phase Angle** (Φ) = **119.4 deg**
- **o Max Angular Rate** (ω) = **281.3** mrad/s
- **o Max Angular Accel (et) = 51.4** mrad/s/s

- o Aim Angie (Θ) = 33.3 deg
- o **Initial Delivery** Error Ellipse:
  - **SMAA = 249.6 km (30)**
  - **SMIA** = 154.9 km (3σ)
  - Θ–**smaa** = -30.2 deg

TOUTATIS RADAR IMAGES

- RADAR IMAGES OFASTEROID4179, TOUTATIS, WERE MADE DURING THE OBJECT'S RECENT CLOSE APPROACH TO'EARTH IN DECEMBER 1992

- IMAGES REVEAL THE OBJECT TO BE TWO IRREGULARLY SHAPED, CRATERED BODIES ABOUT 4.0 BY 2.5 km IN AVERAGE DIAMETER AND PROBABLY CONNECTED TO ONE ANOTHER

- FOUR FRAMES SHOWN IN THE PICTURE WERE OBTAINED ON DEC. 8,9,10, AND 13 WHILE THE ASTEROID WAS AN AVERAGE 4.0 MILLION KILOMETERS FROM EARTH; THE OBJECT APPEARS IN A DIFFERENT ORIENTATION WITH RESPECT TO THE EARTH ON EACH DAY

- RADAR ILLUMINATION IN THESE IMAGES COMES FROM THE RIGHT OF THE FIGURE SUCH THAT PARTS OF THE OBJECT ARE IN SHADOW AND ARE NOT SEEN

- THIS WORK WAS DONE BY A TEAM OF SCIENTISTS LEAD BY DR. STEVEN OSTRO OF JPL; RADAR OBSERVATIONS OF NEAR EARTH ASTEROIDS ARE FUNDED BY THE PLANETARY ASTRONOMY PROGRAM OF NASA's OFFICE OF SPACE SCIENCE

PRELIMINARY DESIGN FOR PROBE DEPLOYMENT/DELIVERY

015 min. Separation BETWEEN PROBE IMPACT AND SPACECRAFT CLOSEST APPROACH
- SUFFICIENT TIME FOR SMALL PARTICLES TO REACH SPACECRAFT
- SPACECRAFT AT 16000 km AT IMPACT; IMPOVES CHANCES OF EARLY DETECTION OF CRATER WITH HIGH RESOLUTION IMAGER
- IMPACT AND IMAGING EVENTS AFTER LAST SPACECRAFT TRAJECTORY CORRECTION MANEUVER (NOMINALLY AT E-0.5 hr)

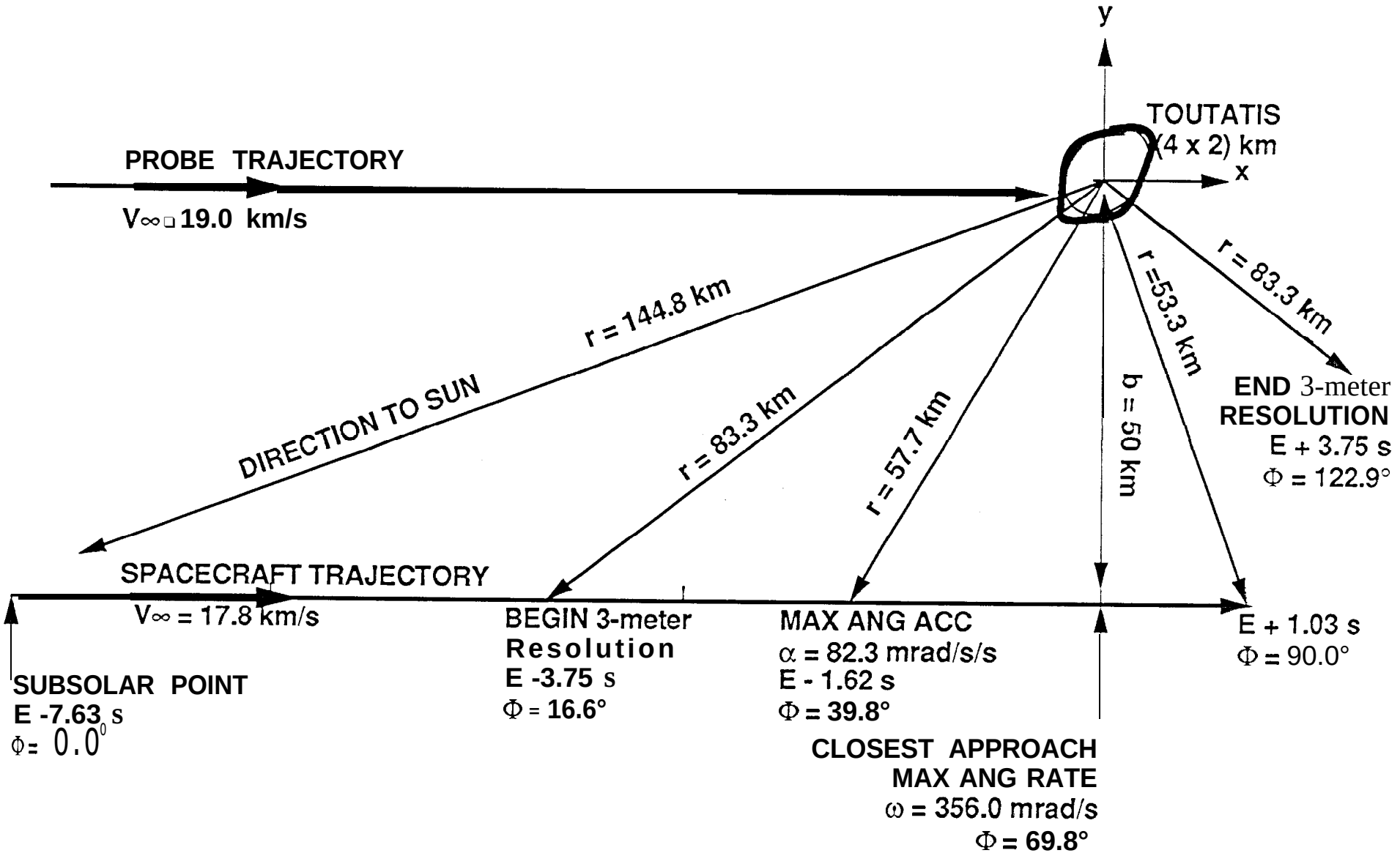
01200 m/s ALLOCATED TO THE PROBE ACCELERATION MANEUVER TO SEPARATE IN TIME THE IMPACT FROM THE CLOSEST APPROACH
- SEPARATION MANEUVER OCCURS AT E-3.96 hr OR 1-3.71 hr
- TARGET ASTEROID SHOULD BE VISIBLE AT ≈3.0 mag
- THREE AUTONOMOUS MANEUVERS BY PROBE AT i -3.0, -2.0,-0.5 hr

TIME (hr)	ΔV (m/s)	DELIVERY ACC.* (km)
-3.0	89.0	58.2
-2.0	8.1	5.7
"0.5	3.2	1.9

o 700 m/s CAPABILITY REMAIN FOR END-GAME GUIDANCE AND CONTROL

•DELIVERY ACCURACY IS THREE-SIGMA, SEMI-MAJOR AXIS OF AIMPLANE ELLIPSE

TOUTATIS ENCOUNTER



- SUNLIT FACE ON APPROACH PROVIDES GOOD IMAGING OPPORTUNITY

- AT 36 μrad SPATIAL RESOLUTION FOR THE HI-RES IMAGER, THE CRATER CAN BE OBSERVED FOR ≈7.5 sec YIELDING AN ESTIMATED 20 HI-RES IMAGES AT VARYING PHASE ANGLES

SUMMARY

o ANALYSIS HAS IDENTIFIED A FEASILBLE AND INTERESTING TRAJECTORY TO ENCOUNTER TWO NEAR EARTH ASTEROIDS: EROS AND TOUTATIS

o DEPLOYMENT OF A PROBE FROM THE SPACECRAFT TO IMPACT TOUTATIS MAY ALSO BE FEASIBLE WITH ADVANCED PROPULSION TO IMPROVE SYSTEM PERFORMANCE

o THIS MISSION WILL PROVIDE AMPLE OPPORTUNITIES TO DEMONSTRATE AUTONOMOUS NAVIGATION AND OTHER TECHNOLOGY TESTS OF INTEREST TO SDIO

o THJS MISSJON WILL PROVIDE NASA SCIENTISTS WITH THE SECOND CLOSE LOOK AT NEAR EARTH ASTEROIDS, CLEMENTINE I BEING THE FIRST WITH iTS FLYBY OF GEOGRAPHOS
  - EROS IS OF INTEREST AND UNIQUE BECAUSE IT IS THE LARGEST OF THE KNOWN NEAR EARTH ASTEROIDS
  - TOUTATIS WAS RECENTLY OBSERVED BY RADAR AND A SPACE MISSION TO ENCOUNTER IT WILL CORROBORATE PREVIOUS DATA
  - THE IMPACTING PROBE AND A PROPERLY INSTRUMENTED SPACE-CRAFT COULD WELL PROVIDE INFORMATION NORMALLY REQUIRING A RENDEZVOUS MISSION